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PERFORMANCE ENHANCEMENT OF LTE NETWORK SYSTEM FUNCTIONALITIES USING MIXED SENSITIVITY CONTROL

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***ABSTRACT:** Long Term Evolution (LTE) networks have problems with Transmission Control Protocol (TCP) low speed implementation. There is a need for adequate compensation in the data transfer function to achieve improved performance. In the work, Mixed Sensitivity control and PID Control techniques were adopted and compared to evaluate network performance on weighted parameters. It was observed that by using three adjustable weighting functions* W_1, W_2 *and* W_3 *to develop a compensator by using mixsyn command, a robust compensator was developed, the damping time measures 0.000407s, and 0.000425s for first and second experiment. The LTE network improvement was also carried out using PID control technique with three control functions* K_p, K_i *and* K_d*, this measures a damping time of 550s and 520s. from the result of the damping time, the Mixsyn recorded a lower time while the PID recorded a much higher time. The work recommends that: TCP based LTE network performance improvement using mixed sensitivity synthesis should be applied in the current LTE networks in order to achieve faster data packet transfer. This work also achieved the application of an adequate compensator that improved the performance and stability characteristics of the LTE Network system functionalities.*

***KEYWORDS:** Compensation, Transmission Control Protocol, Mixsyn, & PID*

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Original Article

1.0 INTRODUCTION

There has been increasing demand for faster and more reliable networks in recent times, so a more robust system that can adequately maintain good performance with good throughput and the ability to withstand traffic congestion and system uncertainties is inevitable,[1]. These necessitate that resources should be efficient and of optimal performance. The Cisco report [2]shows that downloading of data transfer and videotelephony have contributed tremendously towards the rise in data congestion by more than 47% in 2022 compared to that of 2017. This work aims to simulating and analyzing the settling rate of a TCP facilitated LTE wireless network using mixsyn and PID control technique. The objective is to juxtapose the system's feedback with the sole purpose of ascertaining all best control techniques to adopt in an LTE network. The problem in the traditional TCP includes; low speed implementation high latency, which does not support the requirements of the LTE network, data and packet transfer error due to traffic congestion and bufferbloat, which affects the performance of the TCP-based LTE network, TCP established LTE model uncertainties. Fourth Generation Long Term Evolution (4G-LTE) is the third Generation Partnership Project (3GPP) and a packet switched all-IP wireless protocol that evolved from UMTS and GSM [3]. TCP performance in mobile networks have been studied in [4], the study shows load addition in cell leading to striking bandwidth reduction in UEs, hence degrading the performance of TCP andit's ideal handover results to TCP desolation while ideal handover gives rise to no segments' delay in the TCP.

2.0 OVERVIEW OF LTE WIRELESS MOBILE NETWORK

LTE tends to be a leading OFDMA mobile wireless broadband technology expounded by 3GPP. It introduces a high spectral efficiency as well as poor latency and increased peak data rate.

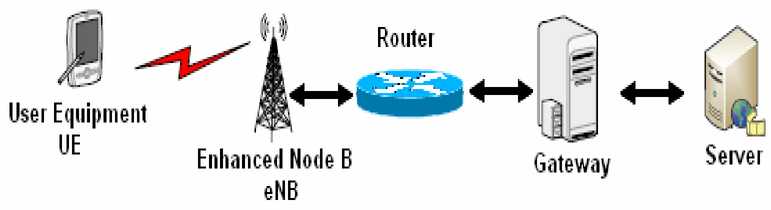

Figure 1: General Representation of 4G-LTE System.

Figure 1, shows the general representation of LTE system.

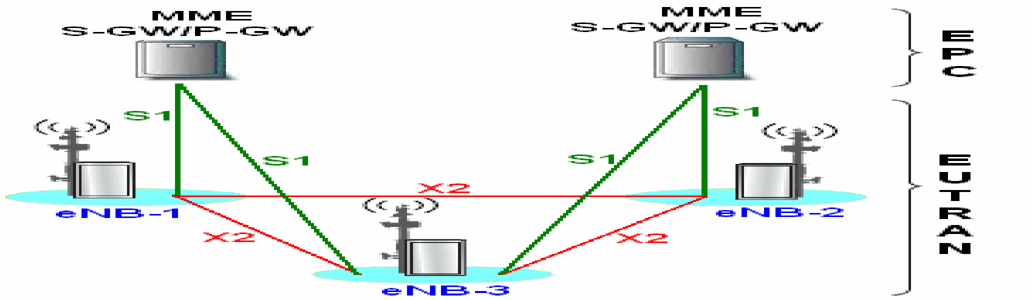

Figure 2: E-UTRAN and EPC Architecture.

The recent step has been examined and expounded in 3GPP is the developed packet-access core network in the SAE and the LTE[5]. Figure 2 shows the EPC and that of the E-UTRAN structure of 3GPP.

E-UTRAN structure with eNB-3, eNB-2 and also eNB-1, shown in Figure 2 is the base station. It performs all radio interface-related functions. MME, S-GW and P-GW are the EPC. The MME represents the MME that Manages mobility, UE identity, and security parameters. The functionalities of MME includes; interaction with the Home subscriber server for authentication and profile download, interaction with the eNB and SGW for SGW selections, tunnel control, paging and handover and lastly, it interacts with SGSN for 2G/3G/LTE networks. S-GW anchors for 3GPP access and 2G/3G/LTE bearer plane interworks and as the anchor point in the visited network. It processes all IP packets to/from UE QoS controls and terminates the interface towards E-UTRAN. The P-GW is the subscriber-aware data plane that anchors all access networks. P-GW anchor both home and visited network for all IP-based access (3GPP or not), as session-based user authentication and as all address allocation for both IPv4 and IPv6 and processes all IP-packets to/from UE QoS control, PCEF, LI. The P-GW finds usability as a Node that terminates the interface towards PDN. Every eNB are linked up to the MME/SAE Gateway by the S1 interface whereas the interface of X2 interconnects all eNBs. For temporary user downlink data U-plain the interface of X2 is used.

2.2 Congestion Control

Device communicating over Internet uses combines both flow control and congestion management mechanism to ascertain the actual magnitude of data the sender places on the network to ensure efficient end-to-end delivery. Flow control

instrument limits dispatching more data to ensure the receiver can process and store them without loss. Also, congestion management mechanism ensures the network is not overwhelmed. TCP is a vastly recognized transport layer protocol with congestion management. Congestion control algorithms (CCAs) dominates the congestion control evolution in recent years. Although, congestion management is also a relevant constituent of the recent and less significantly used transport layer protocols as QUIC [6] and Stream Control Transmission Protocol (SCTP) [7]. Quick UDP internet connection (QUIC) is an exception as it exists on top of UDP, but still in the transport layer. The QUIC is an all-round transport layer network protocol developed by[70] google, executed and deployed in 2012 and declared in 2013 as broadband for experimentation at IETF meeting.

2.3 Queue Overflow

To avoid queue overflow problems when the system is overwhelmed, the service providers have to install Bigger capacity buffers in the eNodeB as a result of the limited memory[9]. As at the time of congestion in network, packets begins amassing in bigger queue space at eNodeB and await the allocation of resources [10, 11]. This gives rise to an increase in packet delivery time, which will contrally affect the buffer [9]. The problem associated to the loss-filled TCP congestion management is its ability to detect congestion only when packet is lost [12]. This problem is mitigated using delay-filled congestion identification technique known as TCP Vegas and TCP Westwood. It employs round-trip time (RTT) to identify network congestion. Although this technique resolves the problems of packet loss and buffer loat, thou the network bandwidth is not maximally used. Majority of the available TCP congestion control schemes that calculates the network congestion at the senders' end are either reactive congestion management or proactive congestion control management, and few are hybridized using both methods [11].

2.4 TCP Dynamic Mode

The TCP model control was considered based on fluid flow model. The model was considered because it represents the physical system and provides the system parameters that describe its behavior. A mathematical theory for the behavior of the TCP proposed in [13], and simulations carried according to it reveals ana precise match with TCP dynamics. It considers the two possible causes of retransmission: time-outs and a tripartite replica of the ACKs [14]:

$$\dot{W}(t) \approx \frac{1}{R(t)} + \big(1 - Q(W)\big)\left(-\frac{W(t)W\big(t - R(t)\big)}{2R\big(t - R(t)\big)}\right) p\big(t - R(t)\big) + \big(1 - W(t)\big)Q(W)\frac{W\big(t - R(t)\big)}{R\big(t - R(t)\big)} p\big(t - R(t)\big)$$

$$\dot{q}(t) = \sum_{t=1}^{N} \frac{W(t)}{R(t)} - C \tag{1}$$

Where

- W = window size of the TCP
- q = length of the queue
- R = RTT
- C = capacity of the link
- N = number of sessions of the TCP
- p = probability of packet dropping

- t = time

The function Q(W) ascertains the probability that a timeout causes a loss (rather than by a tripartite duplicate ACK), recalling that the window size is debited by W during the time this loss occurred. A clearer articulation is Q(W) = min(1, 3/W). A clearer model overlooks the timeout mechanism but is best for carrying out a small-signal linearization and prepares the system for a control theoretical breakdown. The concluded model is:

$$\dot{W}(t) = \frac{1}{R(t)} - \frac{W(t)W\big(t-R(t)\big)}{2R\big(t-R(t)\big)} p\big(t-R(t)\big)$$

$$\dot{q}(t) = \frac{W(t)}{R(t)} N(t) - C \tag{2}$$

Using (W, q) as the state of the system and p been the input of the system, the operating point (W0, q0, p0) is defined by $\dot{W} = 0$ and $\dot{q} = 0$ then:

$$W_0^2 p_0 = 2 \tag{3}$$

$$W_0 = \frac{R_0 C}{N} \tag{4}$$

$$R_0 = \frac{q_0}{C} + T_p \tag{5}$$

Linearizing equation 2.1 about the operating point to achieve the following equation:

$$\begin{cases} \delta\dot{W}(t) = -\frac{N}{R_0^2 C}\big(\delta W(t) + \delta W(t-R_0)\big) - \frac{R_0 C^2}{2N^2}\delta p(t-R_0) \\ \qquad\qquad \delta\dot{q}(t) = \frac{N}{R_0}\delta W(t) - \frac{1}{R_0}\delta q(t) \end{cases} \tag{6}$$

Where, $\delta\dot{W} = W - W_0,\ \delta\dot{q} = q - q_0$, $\delta\dot{p} = p - p_0$ represent the perturbed variables around the operating point.

Considering typical network conditions the following terms as applied in [84]:

$$\frac{N}{R_0^2} = \frac{1}{W_0 R_0} \ll \frac{1}{R_0}$$

$$\begin{cases} \delta\dot{W}(t) = -\frac{2N}{R_0^2 C}\delta W(t) - \frac{R_0 C^2}{2N^2}\delta P(t-R_0), \\ \qquad \delta\dot{q}(t) = \frac{N}{R_0}\delta W(t) - \frac{1}{R_0}\delta q(t) \end{cases} \tag{7}$$

Taking into consideration the following dynamics and performing Laplace transform on equation 2.7, it gives:

$$\begin{cases} G_W(s) = \dfrac{\frac{R_0 C^2}{2N}}{\left(s + \frac{2N}{R_0^2 C}\right)} \\ G_q(s) = \dfrac{\frac{N}{R_0}}{\left(s + \frac{1}{R_0}\right)} \end{cases} \tag{8}$$

Where $G_W(s)$represents the TCP dynamic model without time delay and $G_q(s)$represents the queue dynamic model.

2.5 Mixed-Sensitivity Synthesis Loop Shaping

The Mixed-sensitivity synthesis loop shaping facilitates H-Infinity controller by concurrently shaping the frequency

responses for tracking, disturbance rejection, noise reduction and robustness, and controller effort. The input to output actions of the system is defined by energy shift from measurement noise, disturbances, reference input which are all external variables to the output variable and the control variable. This approach is a reliable way of balancing the required exchange between performance and sturdiness. To utilize this technique, the required feedback are converted into tripartite weighting functions that which the mixsyn command utilizes to synthesize the controller [15].

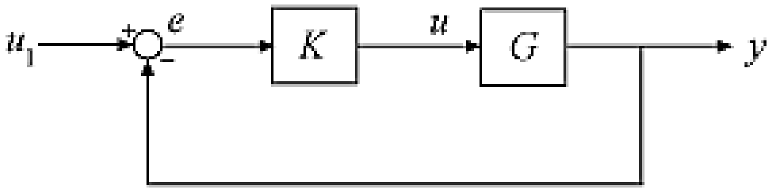

Figure 4: Controlled System.

Figure 1.3 shows the controlled system with the controller K. The synthesis of a controller using the mixed sensitivity configuration requires the choice of three weighting matrices. To realize the K, the function appends the weighting functions provided (i.e. $W_1(s)$, $W_2(s)$, and $W_3(s)$) to the control system, as shown in the diagram in Figure 5.

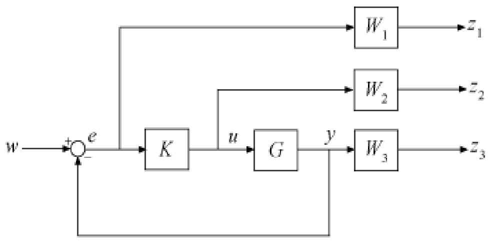

Figure 5: Plant Model for Controlled System with Weights.

Mixsyn then treats the problem as an H_∞ synthesis problem. It analyzes the weighted control system as Linear Fractional Transformation *LFT* (*P*,*K*), where *P* is an augmented plant *P* such that $\{z;e\} = P\{w;u\}$, as shown in the diagram in Figure 5. The augmented plant comprises of the Plant (G) and the Weighting matrix (W_1, W_2, W_3) appended to the various outputs

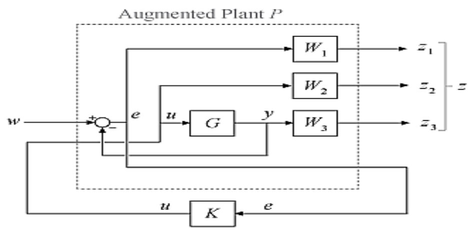

Figure 6: Controlled System with Augmented Plant P.

The transfer function from *w* to *z* can be expressed as;

$$M(s) = \begin{bmatrix} W_1 S \\ W_2 KS \\ W_3 T \end{bmatrix} \tag{9}$$

In instances of mixed sensitivity problem, the main objective is to identify a rational function controller $K(s)$ and to stabilize the closed loop system by reaching the following expression:

$$min\|P\| = min \begin{bmatrix} W_1S \\ W_2KS \\ W_3T \end{bmatrix} = \gamma \tag{10}$$

where, P is the transfer function from w to z i.e.

$$|T_{zw}| = \gamma \tag{11}$$

Where, $|T_{zw}| = P$ been the cost function. Applying the minimum gain theorem, we can make the h-infinity norm of $|T_{zw}|$ less than and equal to unity as expressed in equation 2.12, i.e.,

$$min\|T_{zw}\| = min \begin{bmatrix} W_1S \\ W_2KS \\ W_3T \end{bmatrix} \leq 1 \tag{12}$$

The weights $W_1, W_2\ and\ W_3$ are the tuning parameters and it typically requires some form iterations to obtain weights which will yield a good controller. That being said, a good starting point is to choose:

$$W_1(s) = \frac{\frac{s}{M_S}+\omega_{bs}}{s+\omega_{bs}\varepsilon_S} \tag{13}$$

$$W_2(s) = constant \tag{14}$$

$$W_3(s) = \frac{s+\frac{\omega_{bs}}{M_u}}{\varepsilon_u s+\ \omega_{bu}} \tag{15}$$

Where $\varepsilon_u < 1$ been the maximum value that allows for a steady state offset, $\omega_{bs}\ and\ \omega_{bu}$ is the desired bandwidth and $M_s\ and\ M_u$ is the sensitivity peak (typically,$\varepsilon_u = 0.001\ and\ M_s\ and\ M_u = 2$). The terms W_1S, $W_2KS\ and\ W_3T$ constitute their respective weighting matrices, which allows for range specification of relevant frequencies for the corresponding closed-loop transfer matrix.

Where

$S = (I + GK)^{-1}$ is the output sensitivity transfer function. In [16][23], For stability criterion, if the roots of characteristic equation ensured $1 + GK = 0$ are in left half side of S plane, then stability is ensured. In addition, for Performance Criterion, it establishes that the sensitivity $S = (1 + GK)^{-1}$ is small for all frequencies where disturbances and set point changes are large. Lastly, Robustness criterion, states that stability and performance should be maintained not only for the nominal model but also for a set of neighboring plant models that result from the unavoidable presence of modeling errors. Robust H_∞ controllers are designed to ensure high robustness of linear systems. The Control Sensitivity Function, $T = K(1 + GK)^{-1}$.KS is the transfer function from w to u (the control effort). It is also known as output sensitivity transfer function. T = (I – S) = GK (I + GK)–1 is the complementary sensitivity transfer function. Mixsyn seeks a controller K that minimizes $\|M(s)\|_\infty$ (H_∞ norm (peak gain) of M). To do so, it invokes H-Infinity synthesis (hinfsyn) on the augmented plant:

$$P = aug\ w\ (G, W_1, W_2, W_3) \tag{16}$$

3.0 WEIGHTING FUNCTIONS SELECTION

To choose or select the weighting functions, the following points are followed [15]:

For loop gain $L = GK$, to achieve good reference tracking and disturbance rejection, high loop gain at low

frequency is needed.

To achieve robustness and attenuation of measurement noise, L needed to roll off at high frequency. This loop shape is equivalent to small S at low frequency and small T at high frequency. The design of the weighting matrix WS is intended to provide system robustness with respect to multiplicative output uncertainties, while WT allows required performance conditions to be imposed for the close loop system,

For mixed-sensitivity loop shaping, weighting functions are chosen to specify those target shapes for S and T as well as the control effort KS. The H_∞ design constraint,

$$\|M(s)\|_\infty = \left\| \begin{matrix} W_1 S \\ W_2 KS \\ W_3 T \end{matrix} \right\|_\infty \leq 1 \tag{17}$$

This means that

$$\|S\|_\infty \leq |W_1^{-1}| \tag{18}$$

$$\|KS\|_\infty \leq |W_2^{-1}| \tag{19}$$

$$\|T\|_\infty \leq |W_3^{-1}| \tag{20}$$

Therefore, the weights are set to be equal to the reciprocals of the desired shapes for S, KS, and T. In particular;

For good reference tracking and disturbance-rejection performance, choose W_1 large inside the control bandwidth to obtain small S.

For robustness and noise attenuation, choose W_3 large outside the control bandwidth to obtain small T.

To limit control effort in a particular frequency band, increase the magnitude of W_2 in this frequency band to obtain small KS.

Mixsyn returns the minimum $\|M(s)\|_\infty$ in the output argument gamma. For the returned controller K, then:

$$\|S\|_\infty \leq \gamma|W_1^{-1}| \tag{21}$$

$$\|KS\|_\infty \leq \gamma|W_2^{-1}| \tag{22}$$

$$\|T\|_\infty \leq \gamma|W_3^{-1}| \tag{23}$$

Generally, the H_∞ norm of a transfer function, F, is its maximum value over the complete spectrum, and is represented as:

$$\|F(j\omega)\|_\infty = sup\sigma\big(F(j\omega)\big) \tag{24}$$

Here, σ is the largest singular value of a transfer function. The aim here is to synthesize the controller, which will ensure that the H_∞ norm of the plant transfer function is bounded within limits. Now the main objective is to find a controller K, which, based on the information in error signal (e), generates a control signal u, which counteracts the influence of w on z, thereby minimizing the closed loop norm w to z. This is achievable by bounding the values of $\sigma(S)$ for performance $\sigma(T)$ for robustness.

If control effort is not to be restricted, W_2 can be omitted. In that case, mixsyn minimizes the H_∞ norm of:

$$min_g \|M(K)\| \quad (25)$$

Where M is:

$$M(s) = \begin{bmatrix} W_1 S \\ W_3 T \end{bmatrix} \quad (26)$$

$W_1, and\ W_3,$ are the weighting functions to be specified by the designer. As we know that the ultimate objective of the robust control is to minimize the effect of disturbance on output, where the sensitivity function S and the complementary function T are to be reduced. To achieve this it is enough to minimize the magnitude of $|S|$ and $|T|$ which can be done so by making:

$$|S(j\omega)| < \frac{1}{W_1(j\omega)} \quad (27)$$

And, $|T(j\omega)| < \frac{1}{W_3(j\omega)}$

3.1 Recommendations for Choosing the Models for the Weighting Functions

The papers [16],[17],[15] present some procedures for choosing the weighting functions, reducing the order of the transfer functions and designing the robust controllers using the Matlab Toolbox. Robust control methods are developed in [18],[19] for both linear and nonlinear systems, and approaches of robust control theory based on weighting functions are also addressed in [20].

The robustness performance requirements depend on the sensitivity functions, whose specifications are included in the frequency behavior models. If these sensitivity functions remain inside the imposed limits, the robustness objectives are obtained. Therefore, for a standard second order model, the sensitivity function depends on the damping ratio and natural frequency according to the relation [21].

$$S(s) = \frac{S^2+2\xi\omega_n S}{S^2+2\xi\omega_n S+\omega_n^2} \quad (28)$$

4.0 RESULTS AND ANALYSIS

The analysis results of the TCP based LTE wireless network performance with respect to the data collected is as shown in Figure 7 and Figure 8.

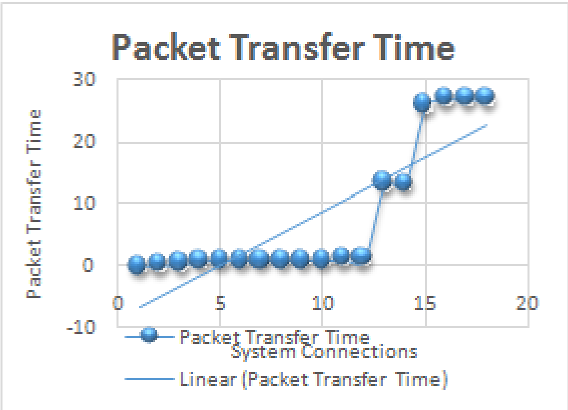

Figure 7: LTE Packet Transfer-Time Result for First Measurement.

The results in Figure 7 show that: The packet transfer time maintained a faster data transfer time when the wireless connections were less than 12 system connections. This means that the LTE system experiences faster data transfer when the network traffic is small. The packet transfer time increased when the wireless connections increased by more than 12 system connections. This means that the TCP based LTE network system speed is affected when the network data transfer traffic increases. This indicates that the LTE network will suffer from traffic congestion when the network traffic increases with heavy data video and voice. This also shows that the LTE network will run very slowly especially when the network traffic increases.

$$y = 1.732x - 8.529 \tag{29}$$

Equation 29, was derived from the straight-line graph of TCP based LTE network packet transfer time results in Figure 7.

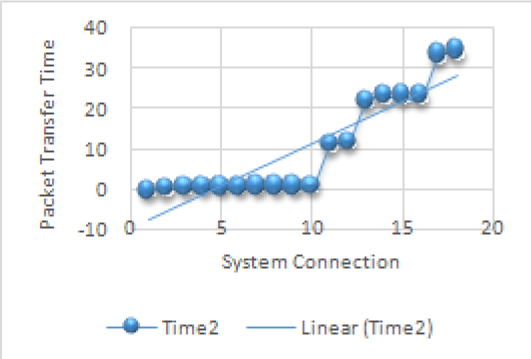

Figure 8: LTE Packet Transfer-Time Result for Second Measurement

The results in Figure 8 shows that: The packet transfer time maintained a faster data transfer time when the wireless connections were less than 10 system connections. This means that the LTE system experiences faster data transfer when the network traffic is small. The packet transfer time increased when the wireless connections increased by more than 10 system connections. This means that the TCP based LTE network system speed is affected when the network data transfer traffic increases. This indicates that the LTE network response is very slow when the traffic increases and when the system connections increases.

$$y = 2.1125x - 9.4652 \tag{30}$$

Equation 30 was derived from the straight line graph of TCP based LTE network packet transfer time results in Figure 8.

4.1 Modified LTE Network Using Mixed Sensitivity Synthesis

The modified LTE network using mixed sensitivity synthesis shows the improved TCP based LTE network performance based on the damping time of the modified LTE system output response. The compensator that can help to improve the LTE network was developed in experiments by modifying the weighting functions.

4.1.1 Experiment I

This was carried out in two scenarios: when the link capacity $(C_L)$is 3750 packets/seconds and 4200 packets/seconds using the weighting functions as expressed as follows:

For link capacity C=3750 packets/seconds, the plant model been:

$$G_P = \frac{25310000000}{s^2+4.002s+0.008} \tag{31}$$

For link capacity C=4200 packets/seconds, the plant model been:

$$G_P = \frac{31750000000}{s^2+4.002s+0.007143} \tag{32}$$

$$W_1 = \frac{1000(0.001s+10)}{s+10} \tag{33}$$

W_1 Been weighting function model at the error signal(e).

$$W_2 = tf\left(\frac{1}{0.1}\right) \tag{34}$$

W_2 Been weighting function model at the control signal (u).

4.1.1 First Scenario of Experiment I, When C=3750 Packets/Seconds

$$C_{k11} = \frac{310317.5S^2+386988.866S+2245222.99eS-266.27e^2+2644667.3e-463130.61}{15+1.5S+0.8579eS+8.5788e} \tag{35}$$

The first scenario of experiment I was carried out using TCP based LTE network link capacity of 3750 packets/seconds:

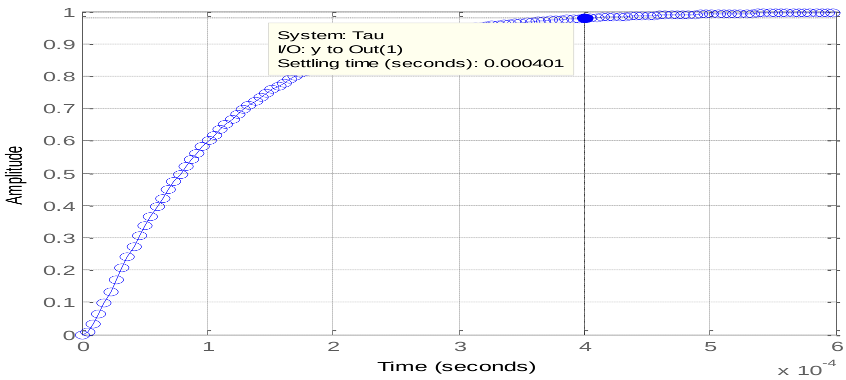

Figure 9: The Time Response of LTE Network When C=3750 Packets/Seconds

The results in Figure 9 show that: The modified LTE network achieved a damping time of 0.000401 seconds. This means that the modified LTE network using mixed sensitivity synthesis achieved a faster system. This indicates that the modified LTE network will cancel the traffic congestion within 0.000401 seconds.

4.1.2 Second Scenario of Experiment 1, When Link Capacity is 4200 Packets/Seconds

$$C_{K12} = \frac{1370247S^2-9516596.6S+4730298.61eS-643.4e^2+643660.96e-1111112.92}{S^3+03S^2-70.8125S+3.418eS^2+34.6495eS-12.8206} \tag{36}$$

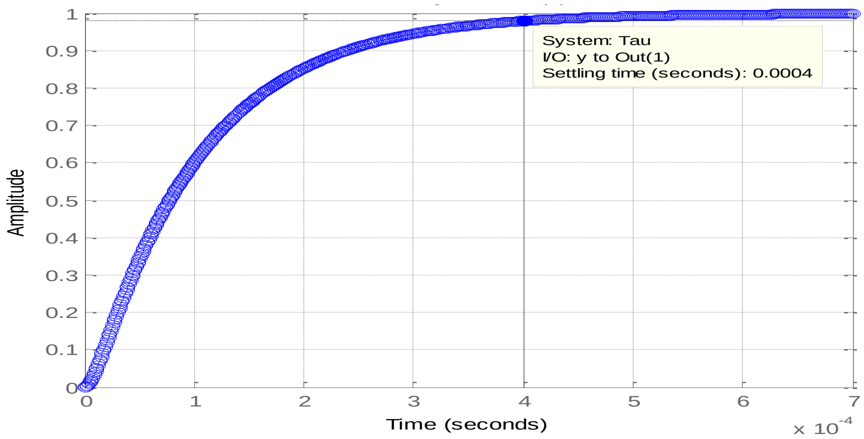

Figure 10: The Time Response of LTE Network When C=4200 Packets/Seconds

The results in Figure 10 shows that: The modified LTE network achieved a damping time of 0.0004 seconds. This means that the modified LTE network using mixed sensitivity synthesis achieved a faster system. This indicates that the modified LTE network will take 0.0004 seconds to cancel the traffic congestion.

The developed compensator C_{K12} using mixed sensitivity synthesis for the second experiment with link capacity C_{L12} of 4200 and weighting functions in Equations 33 and 34 as expressed in state space format as follows:

4.2.2 Experiment II

This was carried out in two scenarios: when the link capacity is 3750 packets/seconds and 4200 packets/seconds using the weighting functions as expressed as follows:

For link capacity C=3750 packets/seconds, the plant model been:

$$G_P = \frac{25310000000}{s^2+4.002s+0.008} \tag{37}$$

For link capacity C=4200 packets/seconds, the plant model been:

$$G_P = \frac{31750000000}{s^2+4.002s+0.007143} \tag{38}$$

$$W_1 = \frac{1000(0.001s+10)}{s+10} \tag{39}$$

W_1 Been weighting function model at the error signal(e).

$$W_2 = tf\left(\frac{1}{0.01}\right) \tag{40}$$

W_2 Been weighting function model at the control signal (u).

The first scenario of experiment I was carried out using TCP based LTE network link capacity G_L3750 packets/seconds and 4200 packets/seconds respectively:

4.2.2.1 First Scenario of Experiment II, when C=3750 Packets/Seconds

$$C_{k21} = \frac{10376S^2+60364.28S-12659.14eS+3790.90e^2+118.33e-10421.54}{1.375S-0.36525eS-3.6525e+13.75} \tag{41}$$

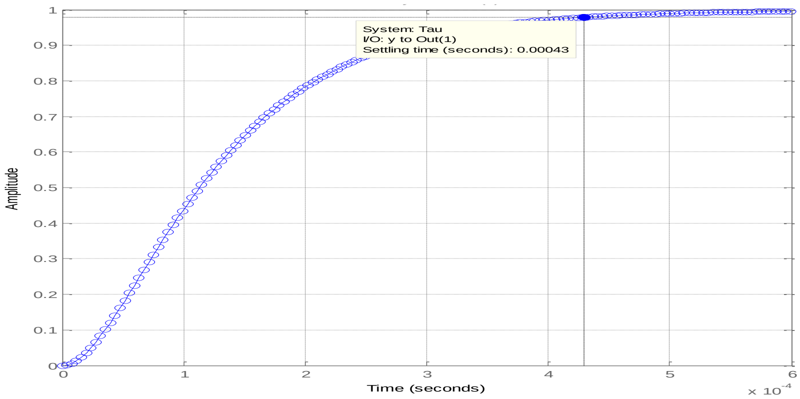

Figure 11: The Time Response of LTE Network when C=3750 Packets/Seconds

The results in Figure 11 show that: The modified LTE network achieved a damping time of 0.00043 seconds. This means that the modified LTE network using mixed sensitivity synthesis will achieve a fast packet transfer. This indicates that the modified LTE network will take 0.00043 seconds to cancel the traffic congestion.

The developed compensator C_{k21} using mixed sensitivity synthesis for the first experiment with a link capacity of 3750 packets/seconds and weighting functions in Equations 39 and 40 expressed in state space as follows:

4.2.2.2 Second Scenario of Experiment II, when C=4200 Packets/Seconds

$$C_{K22} = \frac{13496360S^2 - 8.575486.5S + 21280430.4eS - 785.8e^2 + 7872972.37e - 9343691.25}{S^3 + 04S^2 + 60S + 16.2289eS + 1.565eS^2 + 5.7889} \tag{42}$$

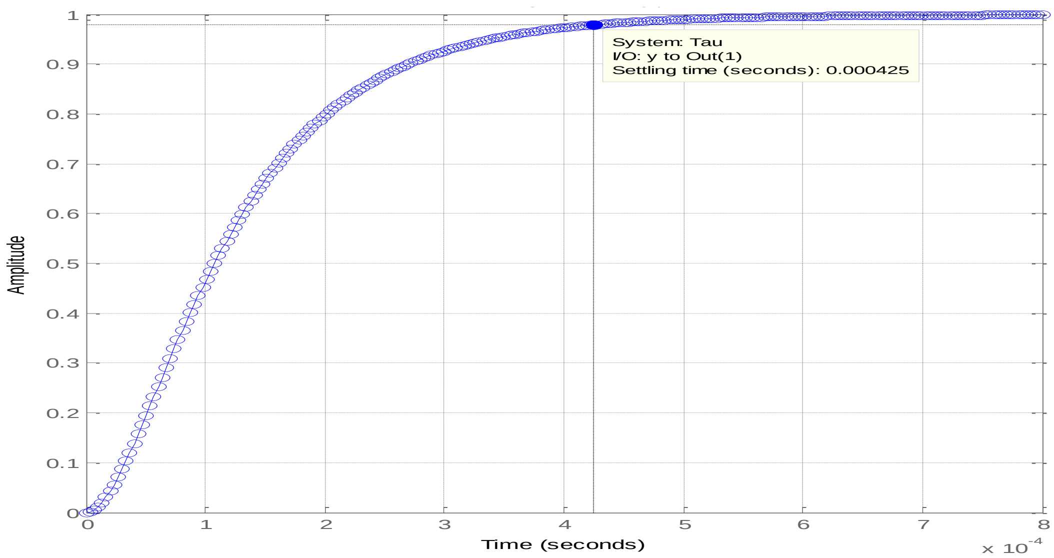

Figure12: The Time Response of LTE Network when C=4200 Packets/Seconds

The results in Figure 12 show that: The modified LTE network achieved a damping time of 0.000425 seconds. This means that the modified LTE network using mixed sensitivity synthesis will achieve a fast packet transfer. This indicates that the modified LTE network will take 0.000425 seconds to cancel the traffic congestion.

The developed compensator C_{K22} using mixed sensitivity synthesis for the second experiment with a link capacity of 4200 packets/seconds.

The first experiment recorded the lowest damping time, which indicates faster time. This is because a robust

system maintains close range of output behavior even when there is a change or variation in its parameter value. The second experiment of the LTE network improvement recorded 0.00043seconds and 0.000425 seconds in the first and second scenarios respectively when link capacity is 3750 packets/seconds and 4200 packets/seconds. This means that the LTE network improvement using mixed sensitivity synthesis maintained good and close range performance parameter values, which indicate that it achieved better performance and robustness than the first experiment.

4.3 TCP over LTE Network Performance using PID Control

The LTE network modification for performance improvement using PID control technique which is termed TCP-PID based LTE network model was carried out in two scenarios: when the link capacity is 3750 packets/seconds and 4200 packets/seconds.

4.3.1 First Scenario - when C=3750 Packets/Seconds

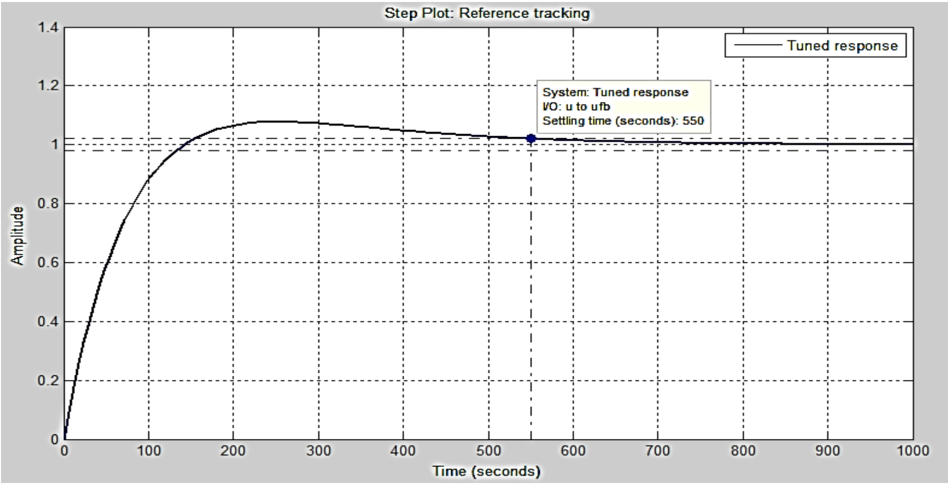

Figure 13: The Time Response of for TCP-PID Based LTE Network when C=3750 Packets/Seconds

The results in Figure 13 show that: The modified LTE network achieved a damping time of 550 seconds. This means that the modified LTE network using the PID control technique achieved a slower system. This indicates that the modified LTE network will cancel the traffic congestion within 550 seconds. The damping time recorded by the TCP-PID based LTE network is very high. This can cause significant loss of data because the slow nature of the network will suffer from high traffic congestion, which will affect the performance of the network. The parameters of the developed compensator Ck using PID control technique for the first scenario with a link capacity of 3750 packets/seconds is expressed in Table 1 as follows:

Table 1: The PID Controller Parameters

PID Parameter	Value
K_p	1.5357e-10
K_i	7.6607e-13
K_d	0

4.3.2 Second Scenario - when C=4200 Packets/Seconds

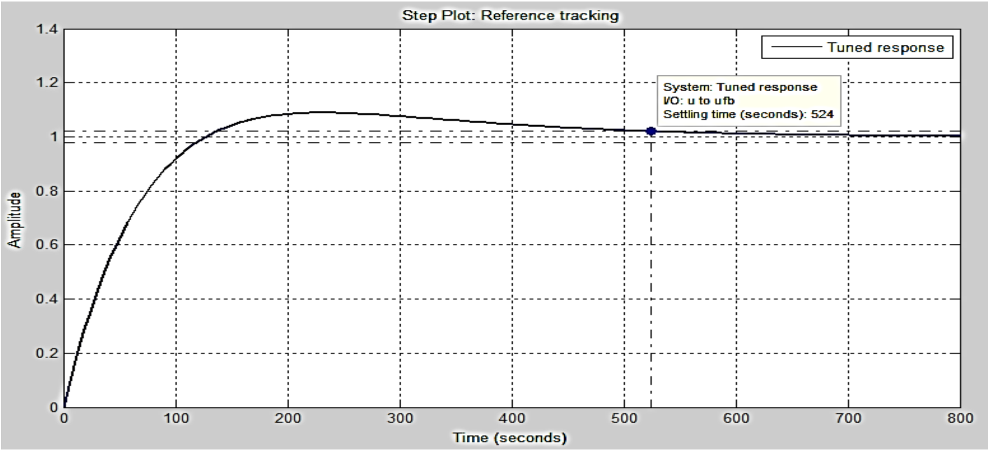

Figure 14: The Time Response of for TCP-PID Based LTE Network When C=4200 Packets/Seconds

The results in Figure 4.18 show that: The modified LTE network achieved a damping time of 524 seconds. This means that the modified LTE network using the PID control technique achieved a slower system when the link capacity is 4200 packets/seconds. This indicates that the modified LTE network will cancel the traffic congestion within 524 seconds. The damping time recorded by the TCP-PID based LTE network is also very high. This can cause significant loss of data because the slow nature of the network will suffer from high traffic congestion, which will affect the performance of the network.

Table 2: The PID Controller Parameters for Second Scenario.

PID Parameter	Value
K_p	1.3177e-10
K_i	7.004e-13
K_d	0

CONCLUSIONS

The LTE network model performance improvement was carried out using mixed sensitivity synthesis which is a robust control technique, which uses three adjustable weighting functions implemented by the mixsyn command to develop a compensation function that is used to modify the TCP based LTE network model. The LTE network improvement was also carried out using the PID control technique with three control functions such as proportional, integral and derivative to improve the system. The LTE network improvement using mixed sensitivity synthesis recorded a damping time of 0.00043 seconds and 0.00042 seconds when the link capacity is 3750 packets/second and 4200 packets/second respectively. While the LTE network improvement using the PID control technique recorded a damping time of 550 seconds and 524 seconds when the link capacity is 3750 packets/second and 4200 packets/second respectively. The LTE network improvement using mixed sensitivity synthesis achieved better damping time than the PID control technique. This indicates that the mixed sensitivity synthesis will address traffic congestion issues better than the PID control technique.

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